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A HUMAN BALLISTIC MORTALITY MODEL

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A model that predicts the mortality rate of soldiers exposed to a ballistic threat has been developed. This model considers the interdependence of the different organs by incorporating an addition rule for adding the damages suffered by different organs. A method for obtaining the necessary vulnerability data is outlined. A computerized Monte Carlo solution of the model is briefly outlined in this report and will be developed more fully in a later BRL report. A sample problem is solved in an appendix to the report.

TABLE OF CONTENTS

		Page
I.	INTRODUCTION	5
II.	THE HUMAN MORTALITY MODEL	8
III.	CONCLUSIONS	19
	APPENDIX	21
	DISTRIBUTION LIST	31

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I. INTRODUCTION

A methodology for calculating the incapacitation probability of a large group of humans, who are exposed to a common ballistic threat, has been proposed.[1] This methodology would analyze the physiological detail of representative wounds that would be produced in the threatened humans. An anatomical description of the average human would be constructed and a phantom of the human would serve as the target in the computerized enactment of battle scenarios. A quantitative assessment of the vulnerability of each organ and tissue to ballistic damage would also be collected and provided to the computer program. The product of the volume of destroyed tissue in each organ and the vulnerability assessment of the organ would be accumulated for the total wound and used to predict the incapacitation probability. However, reference 1 does not define the quantification of the vulnerability of the different organs to ballistic damage.

Earlier incapacitation models did not analyze the physiological detail of the target human. One of the earliest models, developed by Dziemian,[2] correlated the incapacitation probabilities of a set of projectiles with the kinetic energies deposited by the projectiles while penetrating from 1 to 15 cm of tissue simulant (gelatin). The arguments for using that correlation were twofold:

1. The severity of a wound is proportional to the energy deposition of the projectile in tissue.

2. The vital organs in the majority of torso wounds will be reached for penetrations that lie in the 1 to 15 cm range.

This $\overline{\Delta KE}$-Model (pronounced Delta KE) expressed the P(I/H) [probability of incapacitation given a hit] as:

$$P(I/H) = \frac{1}{1 + e^{-(a+b \cdot \overline{\Delta KE})}} \qquad (1)$$

This model was later extended by Sturdivan et al,[3] using a different set of projectiles, to obtain a different parametric relation:

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1. *W. Kokinakis and W. Bruchey, Jr., "An Engineering Approach to the Assessment of Personnel Vulnerability," Vulnerability/Survivability Symposium, American Defense Preparedness Association, October, 1975.*

2. *A.D. Dziemian, "A Provisional Criteria for Fragments and Projectiles," Chemical Warfare Lab R 2391, May 1960 (SECRET).*

3. *L.M. Sturdivan, W.J. Bruchey, Jr., and D.K. Wyman, "Terminal Behavior of the 5.56MM M193 Ball Bullet in Soft Targets," BRL R 1447, August 1969, (SECRET).* (AD #505282)

$$P(I/H) = 1 - e^{c \cdot \overline{\Delta KE}^{d}} \qquad (2)$$

The variables used in equations 1 and 2 are defined as:

$\overline{\Delta KE}$ = the kinetic energy deposited in gelatin by the projectile while penetrating from 1 to 15 cm.

a,b,c,d = curve-fitting parameters evaluated by fitting function 1 and 2 to a set of paired ΔKE and assessed P(I/H) points.

Sturdivan[4] attempted to improve the former models by replacing the independent variable $\overline{\Delta KE}$ by the variable $\overline{EKE}$. The quantity $\overline{EKE}$ for a projectile is the mean energy that would be deposited by a large number of the projectiles, each possessing the desired energy, that impact an average human. The WDMET (Wound Data Munitions Effectiveness Team) hit distribution, based on Viet Nam casualties,[5] was used to locate the wounds. The parametric relation ultimately derived was:

$$P(I/H) = \frac{1}{[1 + a(\frac{\overline{EKE}}{c}) - 1)^{-b}]} \qquad (3)$$

where the curve-fitting constants a,b and c were evaluated in a manner similar to that used in equations 1 and 2. Some controversy[6] arose concerning the general usefulness of using the WDMET distribution and some other hit distribution may eventually be used to calculate the curve-fitting parameters.

The true P(I/H) of a human exposed to a ballistic threat is a function of both the threat and the physiological and geometric detail of the human. The damage incurred by an organ is assumed to be approximated by the energy deposited by the projectile in the organ. The P(I/H) due to a projectile that usually deposits a large fraction of its energy in the more vulnerable organs would be greater than the P(I/H) of a projectile that usually deposits most of its energy into less vulnerable organs even though the total energy deposition is the same in each case. The P(I/H) due to a projectile will, in general, tend to increase with increasing impacting energy.

4. *L.M. Sturdivan, "Handbook on Human Vulnerability Criteria," unpublished, 1976.*

5. *"Evaluation of Wound Data on Munition Effectiveness in Viet Nam," Vol II, Joint Technical Coordinating Group for Munition Effectiveness," December 1970, (CONFIDENTIAL).*

6. *W. Kokinakis, private communication.*

The $\overline{\Delta KE}$ and $\overline{EKE}$ of a projectile are different functions of the ballistic threat and/or the penetration properties of a human (or gelatin) and will, in general, also increase with increasing impact energy. The ΔKE of a projectile is independent of the shape of the energy-deposition profile as long as the total energy deposited from 1 to 15 cm remains constant. The EKE of a projectile would depend upon the shape of its energy-deposition profile but this dependence would not necessarily correlate with that of the true P(I/H). Therefore, none of the preceding three models can be used to reliably predict differences among the incapacitating probabilities of projectiles that deposit varying amounts of energy in tissues of varying vulnerabilites. These models should be restricted to calculating approximate P(I/H) values where good accuracy is not required.

An effort is made in this study to implement a portion of the methodology proposed in reference 1. A statistical model is developed that can predict the mortality rate of a large group of humans exposed to a ballistic threat by analyzing the physiological detail of the wounds received by individual humans. This model will differ from that proposed in reference 1 in that an arbitrary addition law is assumed for accumulating the damages inflicted on each organ in multi-organ wounds to obtain a total wound damage. The preceding model had assumed that a linear addition law would be adequate. A procedure for evaluating the addition law will also be outlined and discussed.

Humans come in a wide range of size, shape, age, sex, and states of health and physical conditioning. An organ or tissue in an individual may have suffered an earlier injury or disease that influenced its subsequent development (as well as the development of other associated organs). The size of an organ and its vulnerability to ballistic damage may vary from individual to individual. The vulnerability of an organ to ballistic damage may be dependent upon the size of the organ as well as the other human characteristics just enumerated. These factors will all contribute to make the modeling of the human population by one average man into a difficult if not impossible task.

The majority of Army personnel engaged in combat actions are young adult males. Individuals having severe physical handicaps have been screened out and are not inducted into the Army. The remainder who are assigned to a combat role have been trained so that they are healthy and in good condition. This selection and training will greatly reduce the spread in the vital physiological characteristics among the Army fighting men as compared to the spread among individuals in the total population. We will assume that this reduction permits the replacement of a large group of soldiers by an average soldier who is the geometrical average of the group. A phantom of this average soldier may then be constructed and used as the target in computerized battle enactments. The validity of this approximation should be verified when a working methodology has been constructed and an adequate vulnerability data bank has been gathered.

The statistical mortality model, developed in detail in the next section of this report, considers the detailed structural and functional vulnerabilities of the interdependent components (organs) of an average soldier to ballistic damage. Implied quantities relating to the operation of the organs, that are difficult if not impossible to measure, are assumed during the development of the model so that an attempt can be made to explain the incapacitating mechanism. However, the final working version of the model will use only experimentally-measurable quantities.

A probability of kill (M) versus volume of tissue destruction (VI) is defined over the soldier population for each organ. Each of these functions is measured or calculated for those wounds in which only the one organ was appreciably injured. A complete set of these functions is needed for each desired set of medical criteria (the time delay in obtaining medical attention for wounded soldiers and/or the quality of medical attention). A hypothetical example of the effect of the availability of medical attention is displayed in Figure 1 for three different time delays in obtaining medical attention. The survival rate versus time lag is derived from these examples and is displayed in Figure 2.

A damage factor is calculated for each injured organ when the Phantom is inflicted with a multi-organ wound. The damage is defined as the ratio of the tissue destroyed in the organ to a VI-value that is picked from the VI probability density function. A picked VI-value for an organ in the Phantom is assumed to be the VI-value of some soldier. The organ damages are accumulated over the wound using a damage addition rule (discussed in the next section of this report) to obtain a total damage for the wound. A kill is scored when the total damage is one or greater. A survival is scored when the total damage is less than one. A life-expectancy that might be reduced by a severe but non-killing wound is tallied as a survival. Two test problems illustrating these calculations for assumed normal VI-density functions are solved in the Appendix.

II. THE HUMAN MORTALITY MODEL

We will assume that a human is composed of different organs and tissues whose functional roles may be delineated and quantified. The proper functioning of each organ is dependent, to a varying extent, upon the functioning at an adequate output level of each of the other organs. An individual may continue to function after suffering injuries to several organs if all vital organs maintain some output capability. The roles of the organs may generally be divided into four general categories.

1. Production. The organ produces a substance such as enzyme that is used by other organs or processes some material such as waste filtering and removal. Such organs may be visualized as being composed

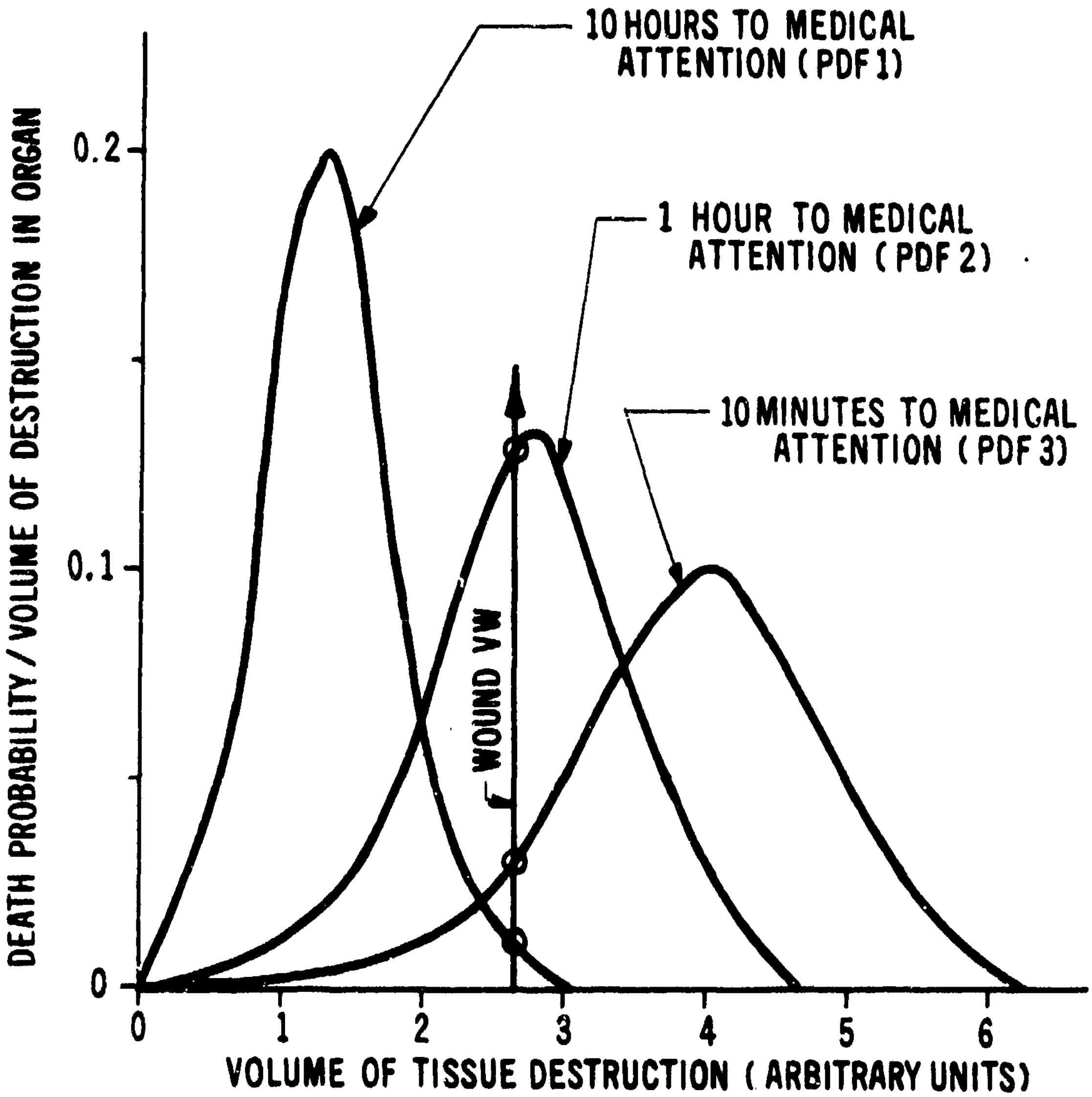

Figure 1. Hypothetical Probability Density Functions for Three Medical Attention Time Delays

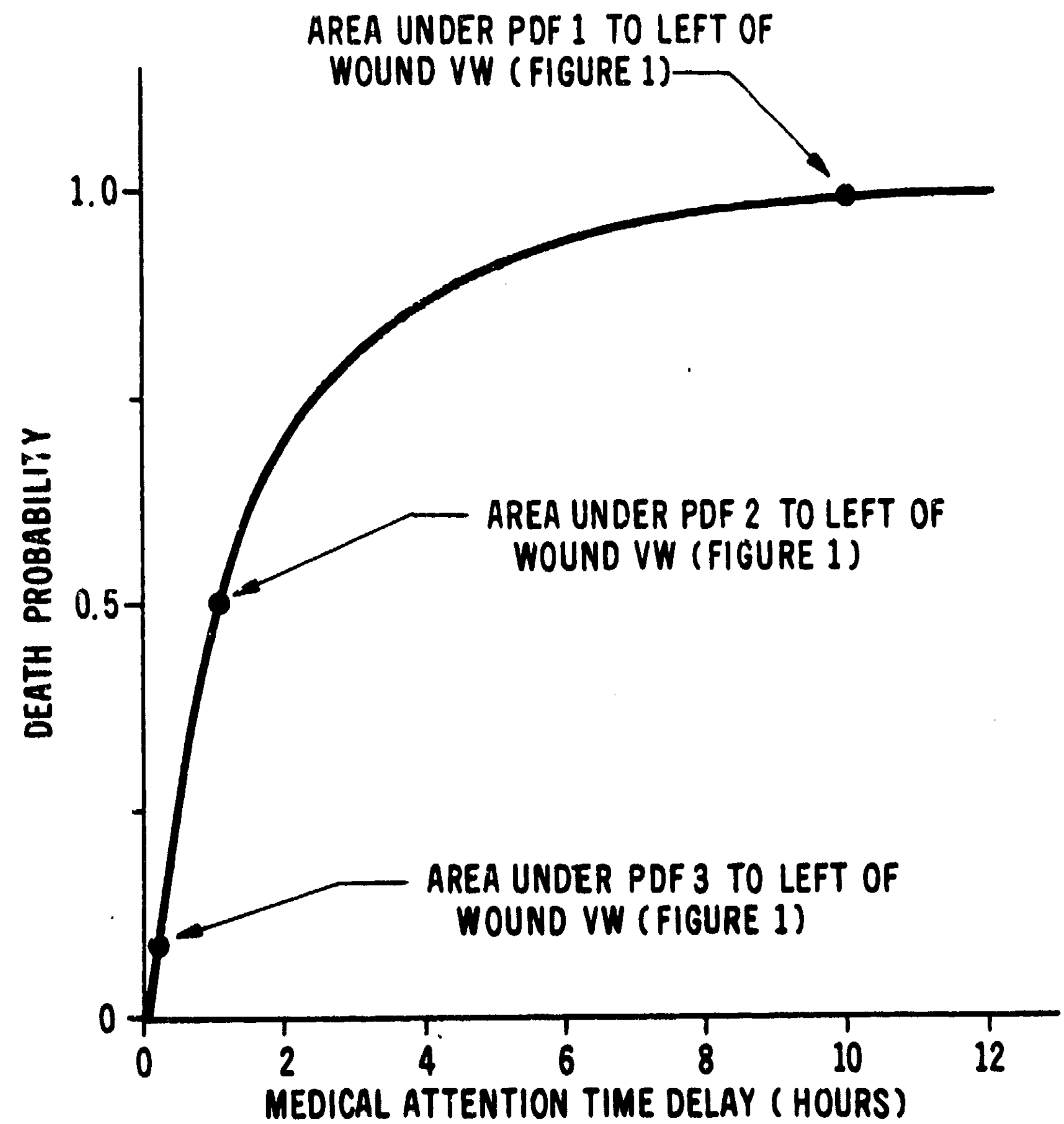

Figure 2. The Death Probability for Wound VW (Figure 1) to an Organ as a Function of Time Delay to Medical Attention

of a large number of small elements where each element plays an identical part in the role of the organ. An injury of this type of organ might remove only part of its output capability.

2. Communication. The spinal cord and major nerve paths would be included in this category. The destruction of a part of the system could lead to the loss of service to large regions of the body.

3. Circulatory. The system of arteries and veins would fall into this category. The destruction of a small part of this network could cause the total system to fail.

4. Mechanical. This category would include structural components such as bones as well as the muscle groups. Damage to this group would be more apt to lead to the inability of an individual to perform a task than to his death.

We will initially develop the mortality model for wounds that involve appreciable damage to only one organ. The existence of an addition law, that may be used to combine the damages inflicted on several organs to obtain the damage produced by the total wound, will then be postulated and the model will be extended to predict the death rate expected from wounds involving more than one organ.

A simple organ to model and analyze would be a production organ that is composed of many small, parallel elements. Damage to such an organ would result in the incapacitation of an individual if a critical fraction of its output capability were destroyed. The death probability as a function of volume of tissue destruction in a soldier who has suffered such a wound is the product of the probability of occurrence of the volume of destruction times the killing probability of the wound. This quantity, when averaged over all such wounds that could be produced by a ballistic threat, is given for the ith organ in the nth soldier by

$$\frac{dM_{in}(VW)}{d(VW)} = \text{change in death probability associated with a change in tissue volume destroyed}$$

$$= \int_{\infty}\int_{\infty} BT\left[S(\vec{r}_1,\vec{p})\rightarrow w\right]\cdot\delta\left[\int_{W} C_{in}(\vec{r}_2)\,dV_2 - DC_{in}\right]\cdot\delta\left[\int_{W} dV_2 - VW\right] dV_1\,dp \qquad (4A)$$

where

$BT\left[S(\vec{r}_1,\vec{p})\rightarrow w\right]$ = the ballistic-threat wound-producing function. Regarded from the stochastic perspective, this function will pick representative projectiles and construct a wound w for each projectile that strikes the soldier. This function will hereafter be abbreviated to $BT(S\rightarrow w)$.

$S(\vec{r}_1, \vec{p} \to w)$ = the projectile source term

$\vec{r}_1$ = the vector, defined in the ballistic threat spatial coordinate system, that locates the origin of a projectile

dV_1 = the infinitesimal volume in the ballistic threat spatial space

$\vec{p}$ = the projectile momentum

dP = the iniinesimal volume in projectile momentum space

$\delta[x-a]$ = the Kronecker delta functional

$C_{in}(\vec{r}_2)$ = the output capability per unit volume of the ith organ in the nth man

$\vec{r}_2$ = the vector, defined in the Phantom spatial coordinate system, that locates a point in the Phantom

dV_2 = the infinitesmal volume in the Phantom spatial space

DC_{in} = the output capability destruction in the ith organ that would lead to the death of the nth soldier

The capability $C_{in}(r\ )$ would be extremely difficult to measure or evaluate for an individual human. Therefore, we will try to transform equation 4A so that the mortality probability will be expressed in terms of variables that can be measured. Firstly, we will assume that the wounds produced in an organ by the majority of the ballistic threats will be distributed uniformly within the volume of the organ. This approximation would imply that the tissue at any point within an organ will be destroyed with equal probability when a large number of hits are averaged. Secondly, we will assume that the ratio of the volume of a lethal wound to the volume of the organ is sufficiently small so that the distribution $\Phi 1(C)$, subsequently defined, does not vary appreciably with wound volume over the wounds of interest. These approximations and assumptions permit equation 4A to be expressed as

$$\frac{dM_{in}(VW)}{d(VW)} \simeq \qquad 4(B)$$

$$\int_{\infty}\int_{\infty} BT(S\ w)\left\{\int_{\infty}\delta\left[C\int_{W} dV_2 - DC_{in}\right]\Phi 1_{in}(C)dC\right\}\delta\left[\int_{W} dV_2 - VW\right]dV_1 dp \tag{4B}$$

where

C = the average output capability of the tissue destroyed in the wound

$\Phi 1_{in}(C)$ = the density function describing the average (when undamaged) output capability of the destroyed tissue. This distribution is assumed to be a slowly varying function of VW and would represent an average over the wound volumes of interest

It should be noted that the density function $\Phi 1_{in}(C)$ as defined here is not necessarily the density function describing the output capability of the different points of the organ. The latter distribution would correspond to the defined $\Phi 1(C)$ when wounds having an infinitesmal volume are the only wounds considered.

Equation 4B may be further transformed to obtain:

$$\frac{dM_{in}(VW)}{d(VW)} \simeq$$

$$\int_{\infty}\int_{\infty} BT(S\to w)\left\{\int_{\infty}\left[\delta\int_{W} dV_2 - VI\right]\Phi 2_{in}(VI)d(VI)\right\}\delta\left[\int_{W} dV_2 - VW\right]dV_1\, dp \tag{4C}$$

$$M_{in}(VW) =$$

$$\int_{\infty}\int_{\infty} BT(S\to w)\left\{\int_{\infty} H\left[\int_{W} dV_2 - VI\right]\Phi 2_{in}(VI)d(VI)\right\}\delta\left[\int_{W} dV_2 - VW\right]dV_1 dp \tag{4D}$$

$$VI = \frac{DC_{in}}{C}, \tag{4E}$$

where

$\Phi 2_{in}(VI)$ = the density function tht describes the incapacitating wound volume VI for the nth individual

$H[x-a]$ = the Heaviside step function

It should be noted that the second assumption is not needed in order that equation 4C be valid. The Heaviside and Kronecker delta functionals are used in equations 4 because of their ready conversion to the anticipated logic of a Monte Carlo computer program that will be written to apply the model to military problems.[7]

The other types of organs will malfunction when they are severed or punctured so as to interrupt their service. Equations 4 may also be used to describe the failure of organs of that type if a critical volume of destruction can be evaluated for each such organ that will predict its failure threshold. We will assume that such a threshold volume can be calculated by using the geometry and physical properties of the organ and the energy deposition profile about the shotline of the projectile. Equations 4 may then be used in subsequent discussions to define death due to any injury where no distinction will be made as to the type of injured organ.

Human organs are, in general, more complex than our idealized descriptions. A complex organ such as the heart, may need to be represented by some combination of serial and parallel smaller elements that display, in microcosm, traits similar to those displayed by the total body. The incapacitating threshold damage volume VI would then need to be evaluated for different regions of some organs instead of being applied to the total organ. The running index i, previously defined as referencing organs, will now be used to reference these subregions of organs.

The density function $\Phi 2_{in}(VI)$ as used in equation 4C and 4D was applied to a particular individual. That development was used to demonstrate that variations in ballistic vulnerability exist over the volume of an organ in an individual. However, the same form of the equation may also be used to express the mortality rate of a large number of individuals where variations in ballistic vulnerability will exist in the same organ among individuals. The mortality rate of the group will now be expressed as:

$$\frac{dM_i(VW)}{d(VW)} = \int_\infty\int_\infty BT(S\rightarrow w)\left\{\int_\infty \delta\left[\int_W dV_2 - VI\right] \Phi 2_i(VI)d(VI)\right\}\delta\left[\int_W dV_2 - VW\right]dV_1 dp \tag{5A}$$

$$M_i(VW) = \int_\infty\int_\infty BR(S\rightarrow w)\left\{\int_\infty H\left[\int_W dV_2 - VW\right]\Phi 2_i(VI)d(VI)\right\}\delta\left[\int_W dV_2 - VW\right]dV_1 dp \tag{5B}$$

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7. *W.B. Beverly, "A Monte Carlo Solution of the Human Ballistic Mortality Problem," to be published as a BRL report.*

where

$\Phi 2_i(VI)$ = the density function that predicts the death-inflicting volume of tissue destruction in the ith organ of the total group of humans

It should be noted that the same variable identification is used for the total group as was used for an individual with the exception of using the upper case $\Phi 2_i(VI)$ to represent the VI-density function of the group of humans. Variations of VI within an organ of an individual and within the same organ of different individuals will be lumped together and will be indistinguishable during calculations. Equation 5 can now be used to predict the probability of death within the group but cannot be used to predict the death of a particular individual.

It is not practical to design laboratory experiments to measure the $\Phi 2_i(VI)$ density distribution of humans. An acceptable method is to analyze hospital gunshot cases where records describing mortality rates and volumes of tissue destruction were collected and maintained. The procedure for evaluating the $\Phi 2_i(VI)$ distribution of an organ using that source of data would be:

1. Collect a data bank of cases, in which only the chosen organ was appreciably injured, that involves members of the selected group of humans. The locations of the wounds should be uniformly distributed over the volume of the organ.

2. Group the cases into continguous, equal-width bins according to the volume of destroyed tissue. Each bin will need a statistically-valid sampling of cases. Construct a histogramic table that gives the mortality rate of each bin.

3. Calculate a least squares fit of the data to an assumed mortality density function. The density function is the derivation of the mortality rate with respect to the volume of tissue destroyed, i.e.,

$$\Phi 2_i(VW) = \frac{dM_i}{d(VW)} \tag{5C}$$

A normal distribution is tractable to analysis and would be a good first choice. The variance and mean VI would be evaluated in the curve-fitting calculation when a normal distribution proves to have been a good choice.

The integral in equation 5B is amenable to evaluation using the Stochastic (Monte Carlo) technique. A brief discussion of a procedure to be used to calculate the death probability that would prevail if the damage to a selected organ is assumed to be the only significant damage suffered by any human is now outlined:

1. Pick a projectile having mass m and momentum $\vec{p}$ and $\vec{r}_1$, using the ballistic threat density functions.

2. Construct a representative wound in the selected organ for these projectiles that damaged the organ.

3. Pick a value of VI from the appropriate distribution $\Phi 2_i(VI)$.

4. Calculate the volume VW of the wound.

5. Score a demise if VW is equal to or greater than VI. Increment the NKILLS tally variable by one when there is a demise.

6. Repeat the process until a statistically-valid number of projectiles NSHOTS have been generated and tracked.

7. The death probability, M_I, for those cases where the damage to the selected organ was sufficient to produce a kill can be calculated using:

$$M_I = \frac{NKILLS}{NSHOTS} \tag{6}$$

The preceding methodology cannot be used for those wounds in which appreciable damage is inflicted upon more than one organ. An addition law, that combines a quantitative measure of the damage suffered by each organ to obtain a quantitative measure of the incapacitating effect of the total wound, must be formulated. To accomplish this objective, we replace the wound volume VW of each organ by the dimensionless damage D_i given by

$$D_i = \frac{VW}{VI_i} \tag{7}$$

This transformation permits equations 5A and 5B to become:

$$\frac{dM_i(VW)}{d(VW)} =$$

$$\int_\infty\int_\infty BT(S\rightarrow w)\left\{\int_W\int_\infty \delta(D_i - 1)\,\Phi 2_i(VI)\,d(VI)\,dV_2\right\}\delta\left[\int_W dV_2 - VW\right]dV_1\,dp \tag{8A}$$

$$M_i(VW) =$$

$$\int_\infty\int_\infty BT(S\rightarrow w)\left\{\int_W\int_\infty H(D_i - 1)\,\Phi 2_i(VI)\,d(VI)\,dV_2\right\}\delta\left[\int_W dV_2 - VW\right]dV_1\,dp \tag{8B}$$

We assume that the damage incurred by a member of the group, who suffers a wound in which more than one organ was appreciably damaged, can be calculated using

$$D_n = F_n(D_{in}) \; , \tag{9}$$

where

$F_n(D_{in})$ = an analytic function that adequately predicts the damage incurred by a human suffering from a multiple-organ wound.

The function $F_n(D_{in})$ will vary from individual to individual since the death probability of an individual suffering a wound would depend upon the general condition and viability of his uninjured organs as well as that of the injured organs. However, we will reintroduce the argument that the vital physiological characteristics of our group of humans does not vary widely among individuals. That argument permits us to make the approximation that the addition law of the different individuals may be averaged to produce an average addition law for the group. The mortality of the group, when each member is inflicted with an identical wound, can then be calculated using:

$$M = \int\int_{\infty} BT(S\ w)\left\{\int_{\infty} H(D - 1)\ \Phi_w(D)dD\right\} dV_1 dp \tag{10A}$$

$$D = F(D_i) \tag{10B}$$

where

$F(D_i)$ = the addition law averaged over the group

$\Phi_w(D)$ = the density function of D when each member of the group (or the Phantom) has suffered an identical wound

It should be noted that the mortality dependence upon the wound volume VW has been removed in equation 10A.

$$= \int_{\infty}\ldots\int \Phi 2_1(VI_1)\ldots\Phi 2_I(VI_I) \int \delta\left[D - F(D_i)\right] dV_2 d(VI_1)\ldots d(VI_I). \tag{11}$$

It should also be noted that the innermost integral of the preceding equation is used to calculate the organ destruction volumes VW_i that are needed to calculate the damages D_i. The quantity D is constant insofar as this integration is concerned and is used in the Kronecker delta functional to evaluate Φ as a function of D. A stochastic solution of the preceding equation is derived in the Appendix of this report for an injury in which two organs are appreciably injured. The distributions $\Phi 2_i(VI_i)$ are assumed to be adequately represented by normal distribution in that example. The solutions to two sample problems are also included in the Appendix.

The addition law can be evaluated by analyzing those hospital gunshot cases in which more than one organ was appreciably damaged. In practice, this analysis could be simplified according to an observation of Sacco and Sturdivan.[8] They stated that the majority of gunshot cases involved appreciable injury to three or fewer organs. This fact would greatly reduce the complexity of an acceptable $F(D_i)$ thus simplifying the analysis.

Susan Baker, et al[9,10] have conducted studies of the blunt trauma victims of automobile accidents in which they concluded that mortality rates could be predicted using a quadratic addition law. They used modified AIS[11] rankings to quantize the severity of injuries instead of our damage quantity but the similarity between the two would justify the use of the quadratic addition rule in this model until a more precise form is determined. Therefore, the addition law that will be used at this time may be expressed as:

$$D = \left[\sum_i^I D_i^2\right]^{1/2} \qquad (12)$$

where

I = the number of organ and tissue types.

Equations 10 were couched in a form that is amenable to solution using the stochastic technique. The procedure will be outlined in detail in reference 7. A brief discussion of that procedure is now given.

1. Pick a projectile having mass $\vec{m}$ and momentum $\vec{p}$ at $\vec{r}_i$ using the ballistic threat density functions.

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8. *W. Sacco and L.M. Sturdivan, private communication.*

9. *S.P. Baker, B. O'Neil, W. Hadden, Jr. and W.B. Long, "The Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care," THE JOURNAL OF TRAUMA, VOL 14, No. 3, 1974.*

10. *S.P. Baker and B. O'Neil, "The Injury Severity Score: An Update," THE JOURNAL OF TRAUMA, VOL 16, No. 11, 1976.*

11. *COMMITTEE OF MEDICAL ASPECTS OF AUTOMOTIVE SAFETY: "Rating the Severity of Tissue Damage I. The Abbreviated Scale," JAMA 215:277-280, 1971.*

2. Construct a representative wound in the Phantom for those projectiles scoring a hit.

3. Pick a value of VI_i for each organ injured using the $\Phi 2_i(VI_i)$ distribution for that organ.

4. Calculate the volume VW_i of destroyed tissue in each organ.

5. Calculate the damage D_i for each damaged organ using equation 7.

6. Calculate the total damage of the wound using equation 10.

7. Score a demise if D is greater than one and increment the kill tally variable NKILLS by one.

8. Generate NSHOT projectiles where the value of NSHOT has been chosen so that the ballistic threat will be adequately sampled. The death probability may then be calculated using:

$$M = \frac{NKILLS}{NSHOTS} \quad . \tag{13}$$

III. CONCLUSIONS

A mathematical formulation of the human ballistic mortality problem has been constructed. The assumptions and approximations that permitted the adoption of the final form of the equations are enumerated. Procedures for obtaining the mortality data that are needed for calculating mortality probabilities are outlined. A proposed Monte Carlo technique for using the model to calcuate mortality probabilities is briefly outlined and will be discussed in detail in a forthcoming report.[7]

Some difficulty will be encountered in obtaining a precise mortality data bank to describe the phantom human. The only source of human mortality data is hospital records where, of necessity, the emphasis of the attending physician is focused upon saving the life of the patient rather than making precise measurements of the wound. The use of live experiments with other animals would require a scaling factor that correlates a wound in an animal with the same wound in a human. The evaluation of such a factor would, within itself, require precise human data. Medical assessments by shock trauma doctors produces data that is biased by the abilities and experiences of the participating doctors. It is expected that the best set of human ballistic vulnerability data will be constructed from all of the data sources mentioned.

The final form of the model must be regarded as tentative until it is placed in an operational status and its predictions are compared with real life events. The obtaining of mortality data of a precision sufficient to permit the incorporation of the model into a working predictive methodology may prove to be an insurmountable obstacle. The author, of course, hopes that the model will prove to be a valid and useful representation of the human ballistic mortality problem.

APPENDIX

A BALLISTIC DAMAGE COMPUTER PROGRAM

APPENDIX

A Basic Computer Program DAMAGE has been written that can be used to calculate an estimate of the damage density function [$\Phi(D)$ in equation 11] when each human in a group has been inflicted with an identical wound that destroyed tissue in two organs. The mortality threshold volume of each organ, VI, is assumed to be defined by a modified normal distribution. The damage incurred by each organ in an individual human is calculated using equation 7 and then added using equation 12 to obtain the total damage. The operation of the program is outlined in the flow chart of Figure A-1 and the listing is given in Table A-I. A dictionary of the variables is given in Table A-II.

The operation of the code is simple. The input data is set in statements as described in the flow chart. A value of VI for each injured organ is picked for an individual human using the rejection technique.[A-1] The total damage is calculated and stored in the appropriate bin of the 128 bins spanning a damage range from 0 to 1.28. This procedure is repeated for a large number of times until a statistically-meaningful estimate of the density function has been accumulated. The results are then printed in tabular form along with identifying captions.

Two sample problems were calculated using DAMAGE and the results were graphed. In the first problem, each individual in the group was assumed to have suffered a wound that destroyed 0.2 units of tissue in organ A and 0.2 units of tissue in organ B. The VI-density functions of the organs were assumed to be given by:

$$\Phi_A(VI) = \frac{1}{\sqrt{2\pi}S_A} e^{-\frac{1}{2}\left[\frac{VI - VI_A}{S_A}\right]^2} \qquad \text{(A1)}$$

$$0 \leq VI \leq 3 \cdot VI_A \ ,$$

$$\Phi_B(VI) = \frac{1}{\sqrt{2\pi}S_A} e^{-\frac{1}{2}\left[\frac{VI - VI_B}{S_B}\right]^2} \qquad \text{(A2)}$$

$$0 \leq VI \leq 3 \cdot VI_B \ ,$$

[A-1] *Y.A. Shreider, "The Monte Carlo Method," Pergamon Press, 1966.*

where

S_A = the standard deviation of VI in organ A,

S_B = the standard deviation of VI in organ B,

VI_A = the mean VI of organ A for the group,

VI_B = the mean VI of organ B for the group.

The standard deviation of VI for each organ was set to 0.1768. The quantitaties VI_A and VI_B were each set to 0.5. Results are displayed in Figure A-2.

The same VI-density functions were used in the second problem. However, each individual was assumed to have suffered a wound that destroyed 0.1 units of tissue in organ A and 0.2646 units of tissue in organ B. These volumes of damage will yield the same total damage as that in Problem 1 when the VI-values in each problem are set to their mean value. The results of the second problem are displayed in Figure A-3.

A kill is scored when the damage in an individual is equal to or greater than 1. In Problem 1, 9999 people were inflicted with an identical wound and 1188 demises occurred. In Problem 2, 9999 people were inflicted with another identical wound and 1095 demises were scored.

The computer program will be useful when data is being analyzed to evaluate damage addition rules. The quadratic addition rule is presently located at statement 210. This statement can easily be revised so that other addition rules can be tried.

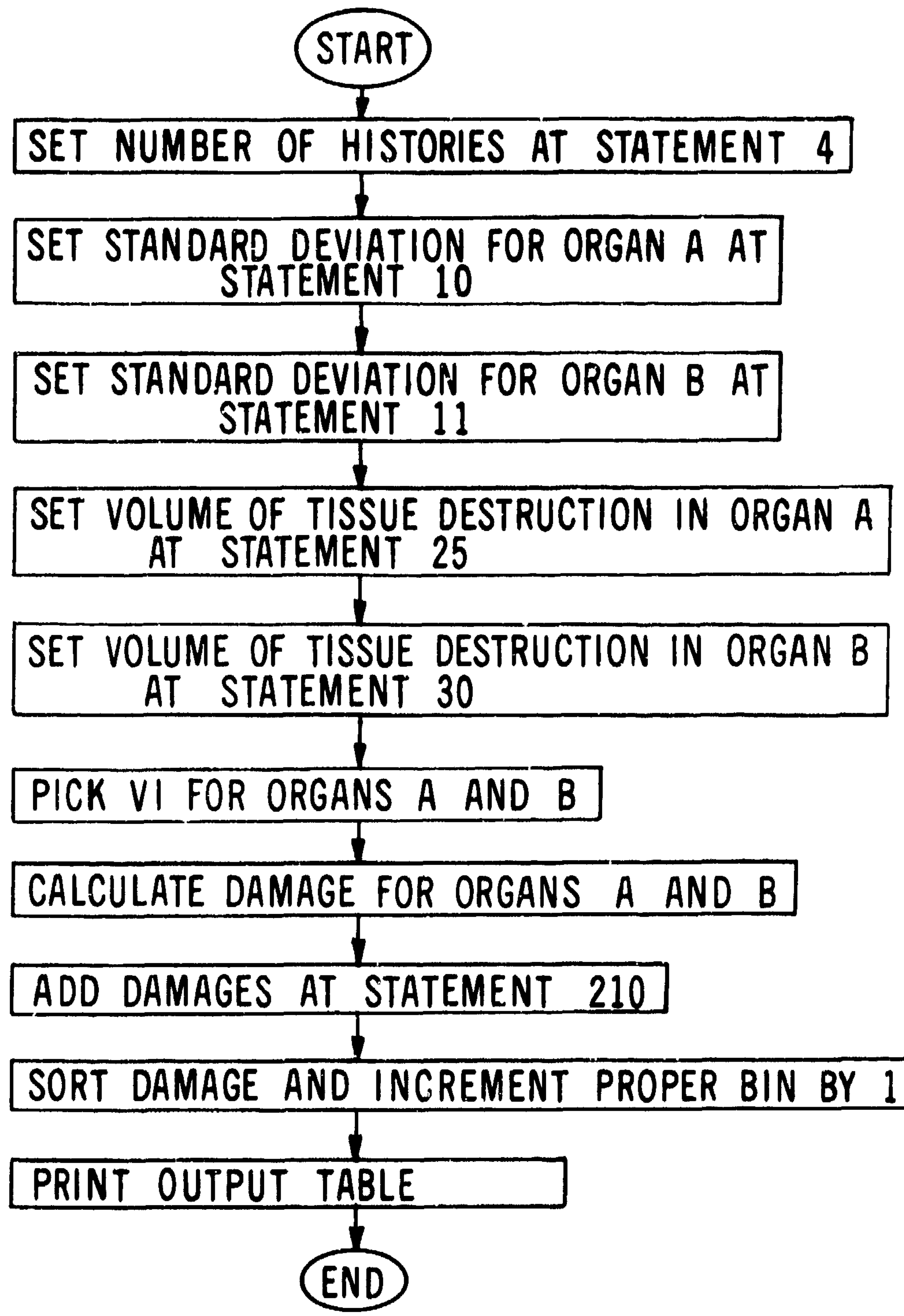

Figure A-1. Damage Flow Chart

Table A-I. Damage Listing

```
1 REM  PROGRAM DAMAGE
2 REM  D^2=D1^2+D2^2
3 DIM C(128): SELECT PRINT 005
4 N1=9999:O1=0: I1=0
10 S1=SQR(.03125)
11 S2=SQR(.03125)
15 V3=0.5
20 V4=0.5
25 W1=0.10
30 W2=0.2646
35 K1=2*3.14159: K1=SQR(K1): K2=K1*S2: K1=K1*S1
50 K1=1/K1: K2=1/K2
60 F1=0: X1=S1: X2=K1: X3=V3
65 I1=I1+1
70 R1=RND(1): R2=RND(1)
80 R2=X2*R2 :R1=3*X3*R1
90 Y=(R1-X3)/X1: Y=-0.5*Y^2: Y=X2*EXP(Y)
130 IF Y<R2THEN 70
140 IF F1=1THEN 180
150 V1=R1
160 F1=1: X1=S2: X2=K2: X3=V4
170 GOTO 70
180 V2=R1
190 D1=W1/V1: D2=W2/V2: D=D1^2+D2^2: D=SQR(D)
200 D2=W2/V2
210 D=D1^2+D2^2
220 D=SQR(D)
221 IF D<=1.28THEN 230
222 O1=O1+1: GOTO 320
230 J1=0: J2=128
240 J=0.5*(J1+J2)
250 IF 0.01*J=DTHEN 310
260 IF 0.01*J>DTHEN 280
270 J1=J: GOTO 290
280 J2=J
290 IF J2-J1>1THEN 240
300 J=J2
310 C(J)=C(J)+1
312 PRINT I1,"THINKING"
320 IF I1<N1THEN 60
321 SELECT PRINT 211
330 Z1$="    DAMAGE": Z2$="    NUMBER": Z3$="CUMULATIVE"
340 PRINTUSING 350,Z1$,Z2$,Z3$
350%      ##########.     ##########     ##########
351 C8=0
360 FOR J1=1TO 128
361 C8=C8+C(J1)
370 PRINTUSING 371,0.01*J1,C(J1),C8
371%      #.####^^^^      ##########     ##########
380 NEXT J1
381 PRINT "OVERFLOWS =",O1
390 END
```

Table A-II. A Dictionary of Code Variables

1.	C	The damage spectrum storage array.
2.	D	The total damage of the wound.
3.	D1	The damage in organ A.
4.	D2	The damage in organ B.
5.	F1	A flag to identify the organ currently being analyzed.
6.	I1	The history index.
7.	K1	The amplitude of the normalized VI - density function of organ A.
8.	K2	The amplitude of the normalized VI - density function of organ B.
9.	R1	Random number between 0 and 1.
10.	R2	Random number between 0 and 1.
11.	S1	The standard deviation of the VI - density function of organ A.
12.	S2	The standard deviation of the VI - density function of organ B.
13.	V1	The VI value picked for organ A.
14.	V2	The VI value picked for organ B.
15.	V3	The mean VI-value for organ A.
16.	V4	The mean VI-value for organ B.
17.	X1	A scratch variable.
18.	X2	A scratch variable.
19.	X3	A scratch variable.
20.	W1	The volume of tissue destroyed in organ A.
21.	W2	The volume of tissue destroyed in organ B.

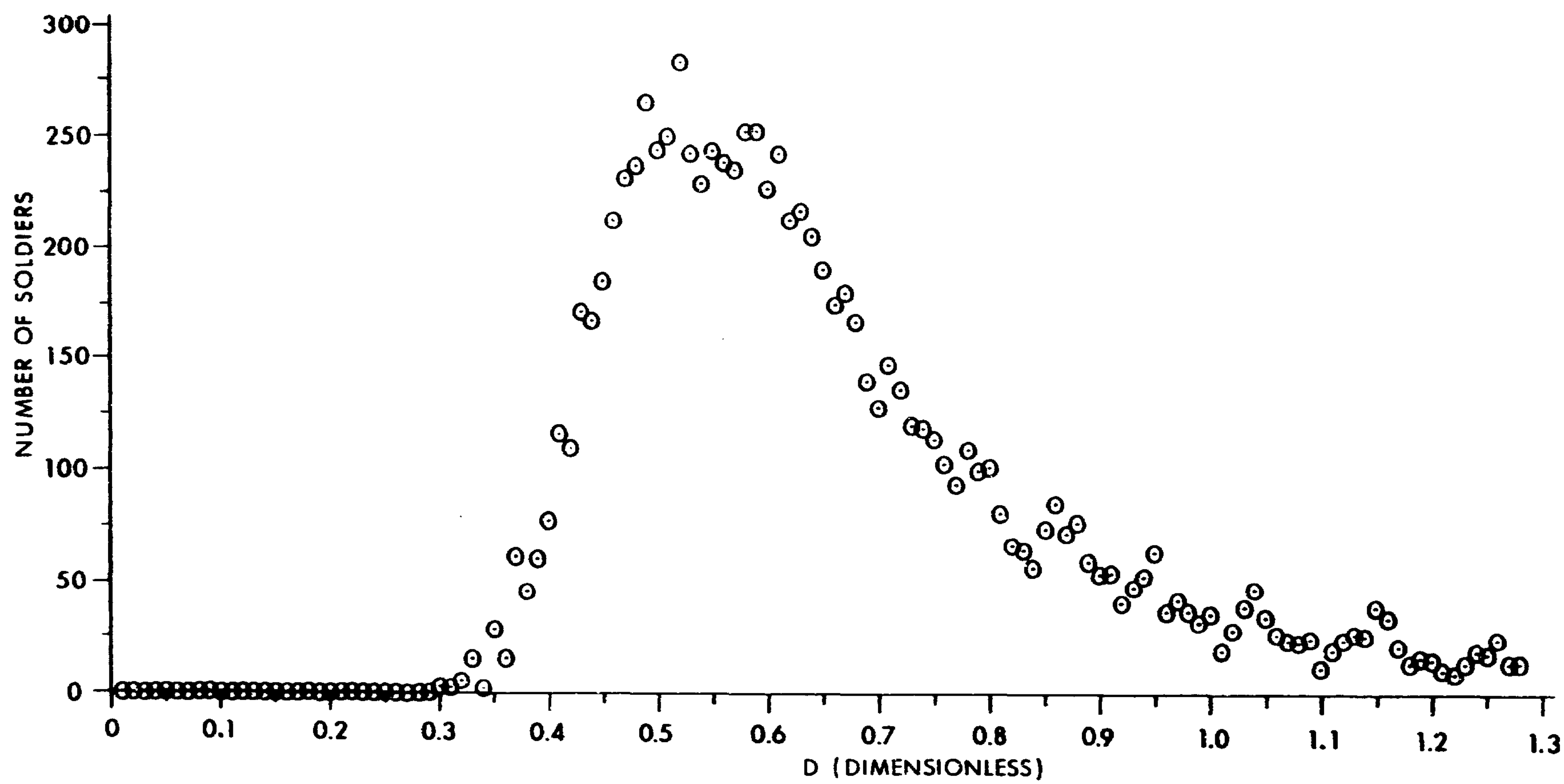

Figure A-2. The Damage Density Function $\Phi(D)$ in the First Problem

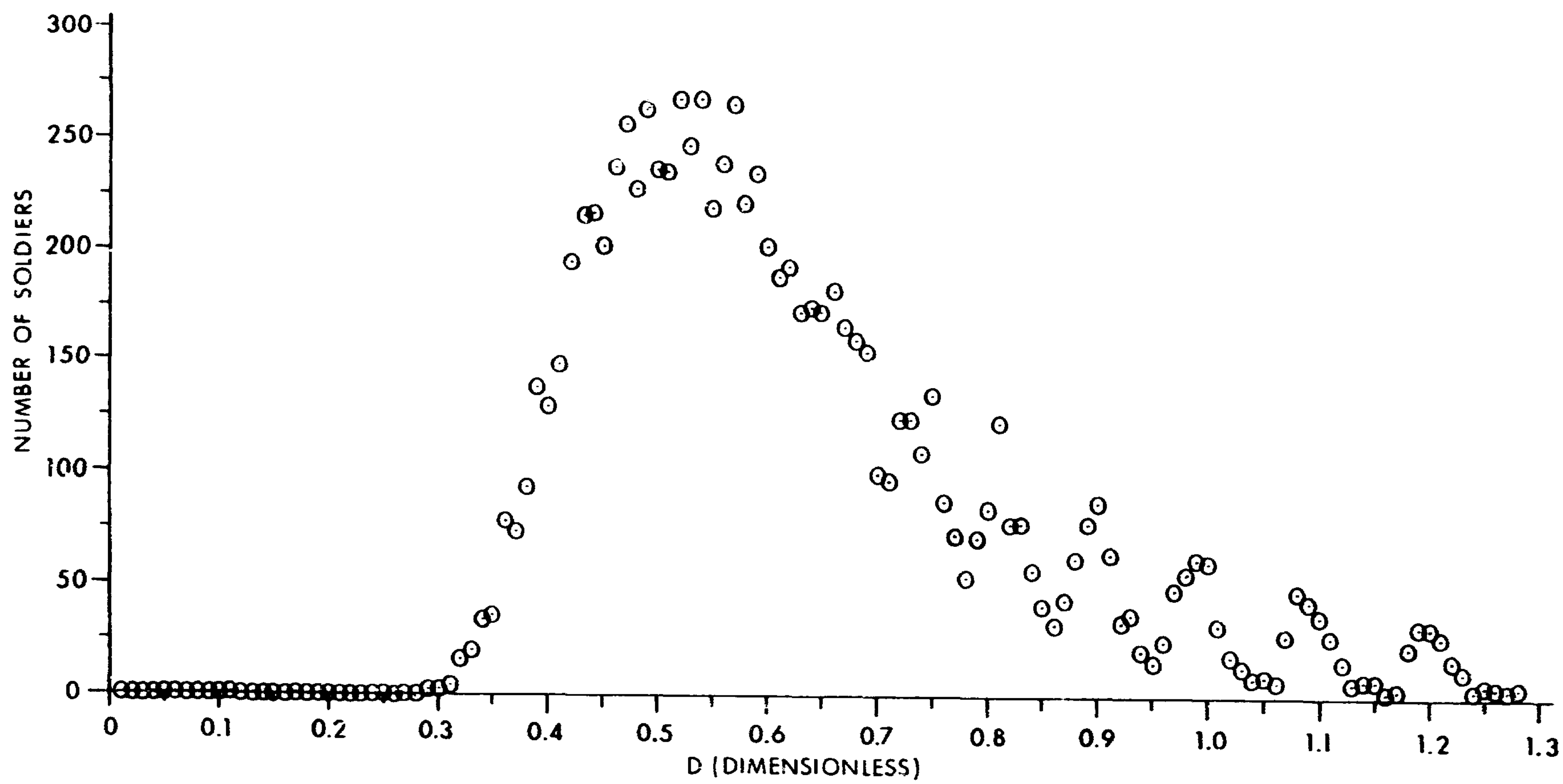

Figure A-3. The Damage Density Function $\Phi(D)$ in the Second Problem

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